ABRASIVE MACHINING PROCESSES

Introduction

Abrasive machining is a material-removal process that involves the interaction of abrasive grits with the workpiece at high speeds and shallow penetration depths. The chips that are formed resemble those formed by other machining processes. Unquestionably, abrasive machining is the oldest of the basic machining processes. Museums abound with examples of utensils, tools, and weapons that ancient peoples produced by rubbing hard stones against softer materials to abrade away unwanted portions, leaving desired shapes. For centuries, only natural abrasives were available, and other, more modern, basic machining, processes, were developed using superior cutting materials. However, the development of manufactured abrasives and a better fundamental understanding of the abrasive machining process have resulted in placing abrasive machining and its variations among the most important of all basic machining processes.

The results that can be obtained by abrasive machining range from the finest and smoothest surfaces produced by any machining process, in which very little material is removed, to rough, coarse surfaces that accompany high material-removal rates. The abrasive particles may be:

1. Free (super finishing operations),
2. Mounted in resin on a belt,
3. Close packed into wheels or stones, with abrasives held together by bonding material (called a grinding wheel).

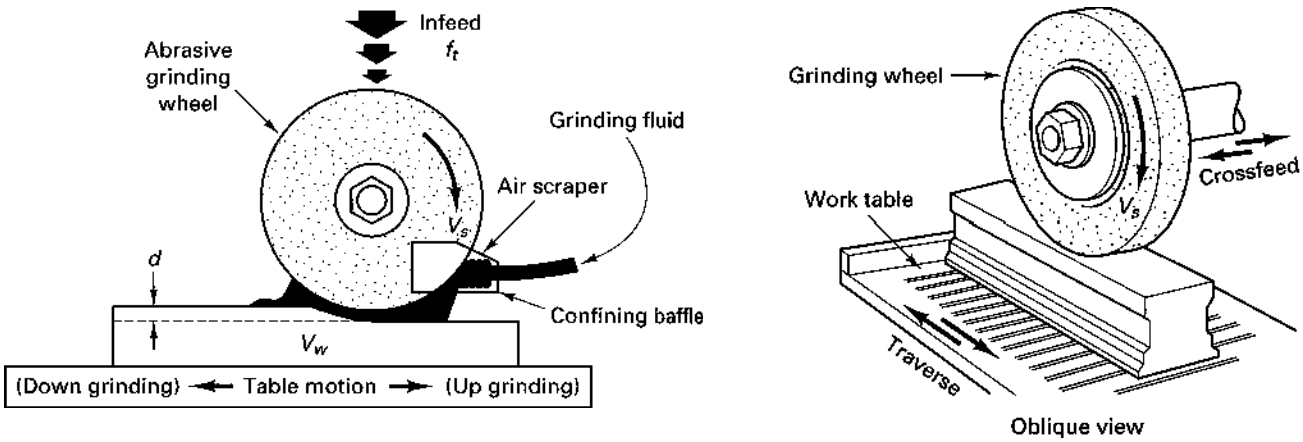


Fig. (1) Schematic of a surface grinding, showing infeed and cross-feed motions along with cutting speeds, Vs, and workpiece velocity, *V.*

Figure (1) shows a surface grinding process using a grinding wheel. The depth of cut is usually very small, 0.05 to 0.125 mm, so the arc of contact (and the chips) is small. The table reciprocates back and forth beneath the rotational wheel. The work feeds into the wheel (see cross-feed direction) after the work has cleared the wheel. The metal-removal process is basically the same in all abrasive machining processes; but with important differences due to spacing of active grains (grains in contact with work) and the rigidity and degree of fixation of the grains.

Abrasive machining processes have two unique characteristics. First, each cutting edge is very small, and many of these edges can cut simultaneously. When suitable machines are employed, very fine cuts are possible and fine surfaces and close dimensional control can be obtained. Second, because extremely hard abrasive grits can be produced, very hard materials, such as hardened steel, carbides, and ceramics, can readily be machined. As a result, the abrasive machining processes are not only important as manufacturing processes, they are indeed essential. Many of our modern products, such as modern machine tools,

automobiles, space vehicles, and aircraft, could not be manufactured without these processes.

Mostly, grinding is the finishing operation because it removes comparatively little material, usually 0.25 to 0.50 mm in most operations and the accuracy in dimensions is up to 5μm and surface finish up to 1 μm.

Abrasive

An *abrasive* is a hard material that can cut or abrade other substances. Natural abrasives have existed from the earliest times. For example, sand stone was used by ancient peoples to sharpen tools and weapons. Early grinding wheels were cut from slabs of sandstone, but because they were not uniform in structure throughout, they wore unevenly and did not produce consistent results. **Emery**, a mixture of alumina (Al_2O_3) and magnetite (Fe_3O_4), is a natural abrasive used on coated paper and cloth. **Corundum** (natural Al_2O_3) and diamonds are other naturally occurring abrasive materials. Today, the only natural abrasives that have commercial importance are quartz, sand, garnets, and diamonds. Quartz sand is used primarily in coated abrasives and in air blasting, but artificial abrasives are also making inroads in these applications. The development of artificial abrasives having known uniform properties has permitted abrasive processes to become a precision manufacturing process.

Hardness, the ability to resist penetration, is the key property for an abrasive. The particles must be able to decompose at elevated temperatures. Two other properties are significant in abrasive grits: **attrition** and **friability**. **Attrition** refers to the abrasive wear action of the grits, resulting in dulled edges, grit flattening, and wheel glazing. **Friability** refers to the fracture of the grits and is the opposite of toughness. In grinding, it is important that grits be able to fracture to expose new, sharp edges.

Diamonds are the hardest of all materials. Those that are used for abrasives are either natural, off-color stones (called garnets) that are not suitable for gems, or small, synthetic stones that are produced specifically for abrasive purposes. Manufactured stones appear to

be somewhat more friable and thus tend to cut faster and cooler. They do not perform as satisfactorily in metal-bonded wheels. Diamond abrasive wheels are used extensively for sharpening carbide and ceramic cutting tools. Diamonds also are used for truing and dressing other types of abrasive wheels. Diamonds are usually used only when cheaper abrasives will not produce the desired results. Garnets are used primarily in the form of very fin crushed and graded powders for fine polishing.

Artificial abrasives date from 1891, when E. G. Acheson, while attempting to produce precious gems, discovered how to make silicon carbide (SiC). Silicon carbide known commercially as **Crystolon** is manufactured inside an electric furnace with silica sand, petroleum coke, salt, and sawdust. As can be seen in Figure (2), the resulting grits, or grains, are circular in shape, with cutting edges having every possible rake angle. Silicon carbide crystals are very hard, friable, and rather brittle. This limits their use. Silicon carbide is sold u the trade names Carborundum and Crystolon.

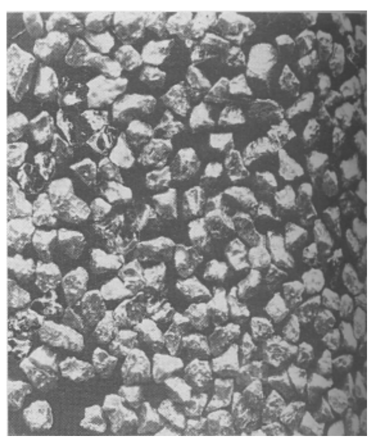


Fig. (2) Loose abrasive grains at high magnification, showing their irregular sharp cutting edges

Aluminum oxide (Al_2O_3), is the most widely used artificial abrasive. Also produced in an arc furnace, from bauxite, iron filings, and small amounts of coke, it contains aluminum hydroxide, ferric oxide, silica, and other impurities. The mass of aluminum oxide that is formed is crushed, and the particles are graded to size. Common trade names for aluminum

oxide abrasives are **Alundum** and **Aloxite**. Although aluminum oxide is softer than silicon carbide, it is considerably tougher. Consequently, it is a better general-purpose abrasive. Cubic boron nitride (CBN) is not found in nature. It is produced by a combinafi of intensive heat and pressure in the presence of a catalyst. CBN is considered the second hardest substance created by nature or manufactured and is often referred to, along with diamonds, as a superabrasive. However, this is not everything, CBN far surpasses diamond in the important characteristic of thermal resistance. When the temperature of 1400°C is reached, CBN changes from its cubic form to a hexagonal form and loses hardness. CBN can be used successfully in grinding iron, steel, alloys of iron, Ni-based alloys, and other materials. CBN works very effectively on hardened materials. CBN does well at conventional grinding speeds (2000 to 4000 m/min), resulting in lower total grinding cost/piece in conventional equipment. CBN can also perform well a high grinding speeds (4000 m/min and higher) and will enhance the benefits from future machine tools. CBN can solve difficult-to-grind jobs, but it also generates cost benefits in many production grinding operations despite its higher cost.

Abrasive Grain Size and Geometry

To enhance the process capability of grinding, abrasive grains are sorted into sizes by mechanical sieving machines. The number of openings per linear inch in a sieve (or screen) through which most of the particles of a particular size can pass determines the grain size as seen in Figure (3).

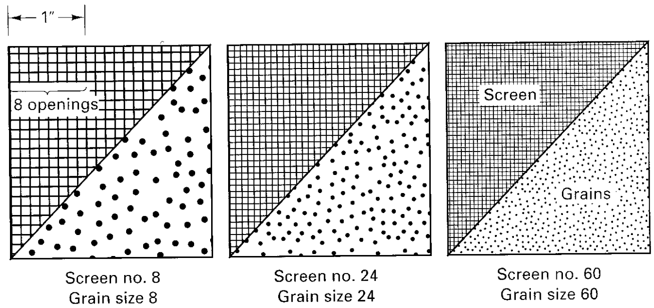


Fig. (3) Typical screens for sorting abrasives into sizes. The larger the screen number (of openings per linear inch), the smaller the grain size

No. 24 grit would pass through a standard screen having 24 openings per inch but would not pass through one having 30 openings per inch. Silicon carbide is obtainable in grit sizes ranging from 2 to 240 and aluminum oxide in sizes from 4 to 240. Superabrasive grit sizes normally range from 120 grit for CBN to 400 grit for diamond. Sizes from 240 to 600 are designated as flour sizes. These are used primarily for lapping or in fine honing stones.

GRAIN SIZES OF NORTON ABRASIVES

Very coarse	8, 10
Coarse	12, 14, 16, 20, 24
Medium	30, 36, 46, 60
Fine	70, 80, 90, 100, 120
Very Fine	150, 180, 220, 240
Flour sizes	280, 320, 400, 500, 600

Regardless of the size of the grain, only a small percentage (2 to 5%) of the surface of the grain is operative at any one time. That is, the depth of cut for an individual grain (the actual feed per grit) with respect to the grain diameter is very small. Thus the chips are

small. As the grain diameter decreases, the number of active grains per unit area increases. The cuts become finer because grain size is the controlling factor for surface finish (roughness).

The grain shape is also important, because it determines the tool geometry that is, the rake and the clearance angle at the cutting edge of the grit. The cavities between the grits provide space for the chips. The volume of the cavities must be greater than the volume of the chips generated during the cut.

Obviously, there is no specific rake angle but rather a distribution of angles. Thus a grinding wheel can present to the surface rake angles ranging from +45° to -60° or greater. Grits with large negative rake angles or rounded cutting edges do not form chips but will rub or plow a groove in the surface (Figures 4 and 5). Thus abrasive machining is a mixture of cutting, plowing, and rubbing with the percentage of each being highly dependent on the geometry of the grit. As the grits are continuously abraded, fractured, or dislodged from the bond, new grits are exposed and the mixture of cutting, plowing, and rubbing is changing continuously. A high percentage of the energy used for rubbing and plowing goes into the workpiece. In cutting, 95 to 98% of the energy (the heat) goes into the chip. Figure (5) shows a scanning electron microscope (SEM) micrograph of a ground surface with a plowing track.

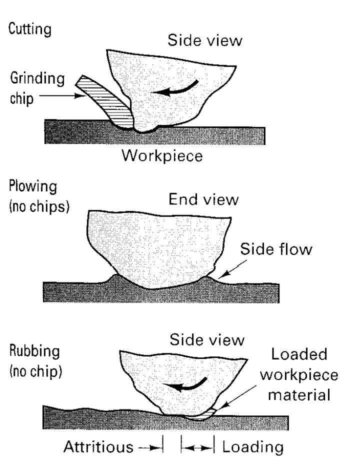


Fig.(4) The grits interact with the surface three ways: cutting, plowing, and rubbing.

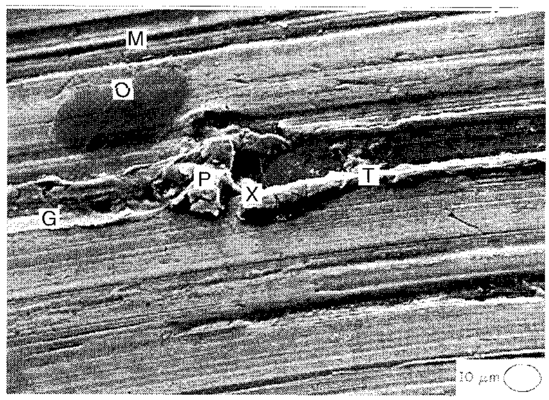


Fig. (5) micrograph of a ground steel surface showing a plowed track (T) in the middle and a machined track (M) above. The grit fractured, leaving a portion of the grit in the surface (X), a prow formation, (P), and a groove (G) where the fractured portion was pushed farther across the surface. The area marked (0) is an oil deposit.

Bond

The other part of the wheel is the binding material (or bond) which holds the particles of grit together. The hardness of the wheel depends in the main on the amount of bond. If the bond is very strong and capable of holding the grains against the considerable force tending to loose them, the wheel is said to be of a hard grade. On the other hand, if only a small force is needed to release the grains, the wheel is said to be of a soft grade.

In Norton method the grade letters increase in hardness from E to Z.

NORTON GRADE LETTERS

Very Soft	E F G
Soft	H I J K
Medium	L M N O
Hard	P Q R S
Very Hard	T U W Z

Grade alone is not an exact value for bond strength. It gives an approximate location in the hardness scale, between two other grades, one of which is harder & the other softer than the grade in question.

Examp1e:

A grade M wheel lies between a grade N & a grade L, but just where it fits into the hardness picture is determined by another variable in the wheel specifications which is called “Structure”.

Structure

It is clear that the grinding action is affected by the spacing of the abrasive grains. Two wheels of the same grain and grade, but differing in there grain spacing will not grind alike. One will cut much faster than the other. By means of structure changes, wheel life can often be increased without reducing the cutting rate.

Higher structure numbers represent wider grain spacing. In the same grain and grade, wheels with higher structure numbers will last longer, generally, than those with the lower numbers.

	STRUCTURE (GRAIN SPACING)
Close spacing	0, 1, 2, 3
Medium spacing	4, 5, 6
Wide spacing	7, 8, 9, 11, 12

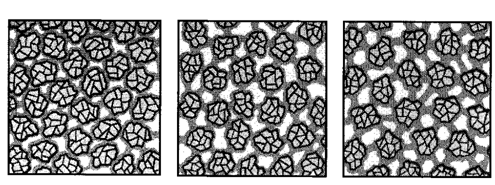


Fig. (6) Meaning of grinding wheel “structure”.

Manufacturing of the Grinding Wheels

Grinding wheels are made by three main processes: Vitrified, Silicate (or semi-vitrified), elastic and rubber processes.

The vitrified process (converts into glasslike substance) produces open texture, free-cutting wheels, which are not affected by weather time, water, oils or acids, and are used for both wet and dry grinding.

The silicate wheels are made by the packing process. They are of larger diameter and greater thickness than the formed by other methods. They are waterproof and are equally serviceable for wet and dry grinding.

Wheels made by the **elastic process** are the only wheels that can be made very thin. The mixture of bond and abrasives is heated and pressed in moulds.

Function of Bond

The function of the bond is not only to hold the particles of the wheel together and to give the wheel the proper factor of safety at the speed it is to be run, but it must also be possible to vary in tensile strength to fit the work it is called upon to do. The wheel is sometimes called too hard or too soft. In the first case the bond retains the cutting teeth so long that they become dulled, and the wheel is inefficient. In the case of a soft wheel, the bond has not been strong enough to hold the cutting teeth and they are pulled out of the wheel before they have done the work expected.

The bond to be used for a given operation depends` on the wheel and work speeds, area of wheel in contact with the work, shape and weight of work, and many other like variables.

The vitrified bond:

It is made of fused clays (Aluminum Silicates), is unchanged by temperature, and can be made in a greater range of hardness than any other bond. It does not completely fill the voids between the grains. Therefore, a wheel bonded in this way, which has more clearance than any other, is adaptable for all kinds of grinding except where the wheel is not thick enough to withstand side pressure. This bond has a high elasticity.

The Silicate bond:

It is not so stable like the vitrified bond as regards damping, and gives less clearance between grains, and has a range of hardness below that of the vitrified in the harder grades. This bond has no elasticity and will not give a safe wheel of extreme thinness. These wheels find their particular field of application in the grinding of fine edged tools, cutters of various kinds.

The elastic bond:

It is composed of elastic coating and other gums. It completely fills the voids of the wheel, has a limited range of grades, has a high tensile strength and elasticity, and can be used for the making of very thin wheels. These wheels are usually used in cutting marble and granite and for finishing cast iron, chilled iron rolls and hardened steel.

The rubber or valcanite bond

It is hard rubber treated with sulphur at high temperature to increase elasticity and strength. It has the general characteristics of the elastic bond but its uses are limited. Rubber wheels are used in cases when a fine finish is required and are exclusively used as regulating wheels in centreless grinding machines. These wheels are only efficient at high speeds and the nature of the bond permits such speeds.

Bakelite

It is a plastic made from formaldehyde and phenol. Such wheels are used for cutting off bar stock of all kinds of steel and can be made very thin. The proportion of bond in a wheel varies from about 10% to 30% of its total volume. As the bind dries during vetrification or baking, it shrinks and fuses on the grains, forming bond links.

Symbols for Bonds

Kind of bond	Symbol
Vitrified bond	blank
Bakelite bond	T
Rubber bond	R
Silicate bond	S
Elastic bond	L or V

Sometimes, as in the case of rubber and bakelite bonds, additional symbols are used following the bond letter. These refer to certain modifications of the bond to cover special requirements.

The five characteristics of a Norton wheel in the order in which they appear in the wheel marking are:

1. Abrasive (kind, i.e., alundum, Crystolon ... etc),
2. Grain (Size of abrasive particles),
3. Grade (Strength of Bond),
4. Structure (Grain spacing),
5. Bond (kind, i.e. vitrified, Bakelite, etc.).

Some manufacturers give the Aluminum Oxide the symbol A and the Silicon carbide the Symbol C.

Chip formation in Grinding

During grinding, the cutting edges of the abrasive grains are dulled. At the moment at which the abrasive grain enters into contact with the surface to be ground, the cutting edge of the grain begins to slide along the surface to be ground without cutting. As a result the metal undergoes elastic and plastic deformations until the deformed metal approaches the face of the cutting grain. In this process a great amount of heat in dissipated. After that moment the cutting edge begins to cut a chip very similar to that cut by a peripheral milling cutter tooth in up milling. The shearing action of the grain is the second stage in the chip formation in grinding.

The heat factor has a great effect on the shape of the chip. This heat is sometimes sufficient to melt the chip, which in this case can have the shape of a solidified drop of metal and does not resemble the usual chip. An analysis of the grinding operation showed that there are many such molted chips, particularly when grinding is carried out with a dulled wheel.

Coolant effect:

The chips removed during grinding get into the pores of the grinding wheel, and can be removed from the wheel surface by the action of the coolant jet. If the chip has a relatively large cross-section (i.e. when the latter exceeds the size of the pores between the grains of the wheel, the chip is pressed into the wheel pores so that the action of the coolant is insufficient. This leads to the dulling of the grinding wheel although the grains can be yet sharp.

The dulling of the grains:

After a short period of service, the tip of the grain is rounded and the force required separating the chip from the material being machined by this grain begins to rise. At a certain stage the grain breaks down forming new tips and its cutting ability is been restored.

This property of abrasive grains to restore their cutting ability is called **self sharpening**. After some time, the self-sharpened grain becomes dulled resulting in increase in the cutting force. The grain destroys itself again restoring its cutting action. Then it is dulled, but this time the height of the grain projects so little above the bond material that it can't be destroyed any longer. The increase of the force, associated with the contact surface increase of the grain and consequently the friction can lead to the separation of the whole grain, exposing a new grain to the grinding action. If the bond however is strong enough to withstand the force increase, the grain would not leave the wheel. As a result, the grain ceases to cut and rubs with great force against the face being machined, causing burns and grinding cracks. The operation if continued would lead to the burning of the ground surface. In this case they say that the wheel is dulled and should be dressed to provide for a new wheel life.

Factors governing the choice of the grinding wheel

The essential factors to be considered in choosing grinding wheel specifications that will do a given job most efficiently are:

1. Materiel to be ground,
2. Amount of stock removed, accuracy and finish required,
3. Area of contact,
4. Type of grinding machine.

Material to be ground:

Alundum wheels are recommended by Norton where the material is neither very brittle nor very easily penetrated, or when the material to be ground is of high tensile strength. Such materials include hard and tough alloy steels, tough alloys of bronze and some aluminum alloys. For materials that are easily penetrated such as wood, and those that hard but very brittle such as

stone, Norton recommends Crystolon wheels. Also the dense granular structure of cast and chilled iron calls for the hard, sharp grains of crystolon abrasive.

As a rule, very hard dense materials require a relatively soft grade of grinding wheel. Hard materials resist the penetration of the abrasive grains and cause them to dull quickly.

Softer grades enable the worn, dull grains to break away and expose new and sharp grains. Hard brittle materials generally require a large number of cutting points in a grinding wheel, for rapid grinding, because the penetration of each grain is so slight. A finer grain size may do the work, but a relatively close spacing of abrasive grains or a dense structure will provide the necessary action when other considerations make it inadvisable to use a finer grain size.

Exceptionally hard materials such as cemented carbides are best ground with open structured wheels. This is explained by the fact that the material is very nearly of the same hardness as the abrasive itself, and wide grain spacing permits a more prompt release of worn abrasive grains than would be possible in a relatively dense wheel.

Soft, tough and ductile materials require a wheel with comparatively wide spacing of grains. This allows the grains to penetrate to a maximum depth, and also provides sufficient clearance for the relatively large chips that are removed.

Amount of stock removed, accuracy and surface required:

Where stock removed is large, coarse grain size and wide grain spacing (open structure) are needed. Fine grains, closely spaced, will be better for accurate finishing. The force on each individual grain is less in the finer, more dense structured wheels.

Area of contact:

The area of contact between the wheel and the work influences the selection of the grain size, grade and structure. Cylindrical grinding offers an example of relatively small area of contact. Therefore the force per unit area is high. Relatively fine grain, closely spaced, distributes the large force over a large number of cutting edges. A grade corresponding to “medium hard” is chosen to prevent too rapid wheel wear if the forces tending to tear the grains out of the wheel are large.

Surface grinding with the flat rim of a cylinder-shaped wheel is an example of large contact area. Although the total force between wheel and work may be high, the force per unit area of contact is relatively small. Grain size and structure are adjusted to meet this condition by the choice of coarse-widely spaced grains, to distribute the small force over small number of cutting edges. A grade in the “soft” end of the range is chosen to permit the grains to be released after they have become dull, as the forces which tend to tear them out of the wheel are light.

Type of grinding machine

Heavy, rigidly constructed machines take softer and more open structured wheels than lighter, more flexible types. Some machines are characterized by greater vibrations than others, calling for finer, harder and denser, structured wheels. Plane surface grinding machines making use of the rim of a cup or cylinder wheel require much softer wheels having a wider spacing of abrasive grains than the plane surface grinding machines using the periphery of a straight or disk wheel.

Grinding Wheel Identification

Most grinding wheels are identified by a standard marking system that has been established by the American National Standards Institute, Inc. This system is illustrated and explained in Figure 7. The first and last symbols in the marking are left to the discretion of

the manufacturer.

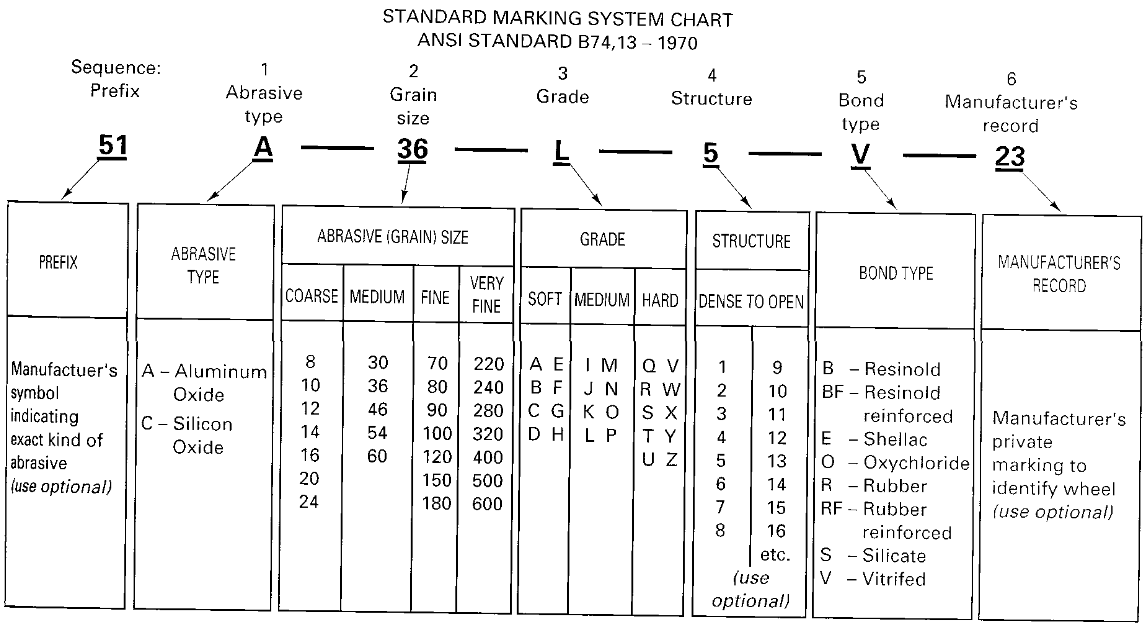


Fig. (7) Identification of a grinding wheel

Dressing and Truing

As the wheel is used, there is a tendency for the wheel to become loaded (metal chips become lodged in the cavities between the grains) and the grains dull or glaze (grits wear, flatten, and polish). Unless the wheel is cleaned and sharpened (or dressed), the wheel will not cut as well and will tend to plow and rub more. Figure 8 shows an arrangement for stick dressing a grinding wheel. The dulled grains cause the cutting forces on the grains to increase, ideally resulting in the grains' fracturing or being pulled out of the bond, thus providing a continuous exposure of sharp cutting edges. Such a continuous action ordinarily will not occur for light feeds and depths of cut. For heavier cuts, grinding wheels do become somewhat self-dressing, but the workpiece may become overheated and turn a bluish temper color (this is called burn) before the wheel reaches a fully dressed condition. A burned

surface, the consequence of an oxide layer formation, results in the scrapping of several workpieces before parts of good quality are ground.

Grinding wheels lose their geometry during use. Truing restores the original shape. A single-point diamond tool can be used to true the wheel while fracturing abrasive grains to expose new grains and new cutting edges on worn, glazed grains (Figure 8). Truing can also be accomplished by grinding the grinding wheel with controlled-path or powered rotary devices using conventional abrasive wheels.

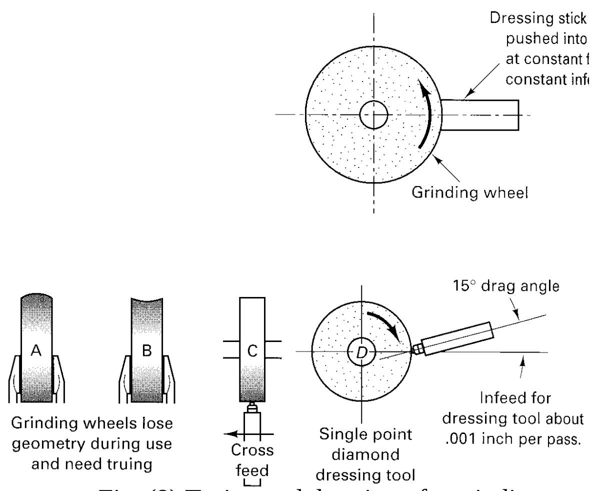


Fig. (8) Truing and dressing of a grinding wheel.

Grinding Machines

Grinding machines commonly are classified according to the type of surface they produce. Grinding is done in the following ways. In the first, the depth of cut is obtained by infeed moving the wheel down into the work or the work up into the wheel. The desired surface in then produced by traversing the wheel across (cross feed) the workpiece or vice versa (surface grinding). In the second method, known, the basic movement is of the wheel being fed radially into the work while the latter revolves an centers. It is similar to form cutting on a lathe (cylindrical grinding).

Cylindrical Grinding

Cylindrical grinding is commonly used for producing external cylindrical surfaces. Figure 9 shows the basic principles and motions of this process. The grinding wheel revolves at an ordinary cutting speed, and the workpiece rotates on centers at a much slower speed, usually from 25 to 40 m/min. The grinding wheel and the workpiece move in opposite directions at their point of contact. The depth of cut is determined by infeed of the wheel or workpiece. Because this motion also determines the finished diameter of the workpiece, accurate control of this movement is required. Provision is made to traverse the workpiece with the wheel or the work can be reciprocated past the wheel. In very large grinders, the wheel is reciprocated because of the massiveness of the work.

A plain center type cylindrical grinder is shown in Figure 9. In this type the work is mounted between headstock and tailstock centers. Solid dead centers are always used in the tailstock, and provision usually is made so that the headstock center can be operated either dead or alive. High precision work usually is ground with a dead headstock center, because this eliminates any possibility that the workpiece will run out of round due to any eccentricity in the headstock.

The table assembly can be reciprocated, in most cases, by using a hydraulic drive. The speed can be varied, and the length of the movement can be controlled by means of adjustable trip dogs.

The longitudinal traverse should be about one-fourth to three-fourths of the wheel width for each revolution of the work. For light machines and fine finishes, it should be held to the smaller end of this range. The depth of cut varies with the purpose of the grinding operation and the finish desired. When grinding is done to obtain accurate size, depths of cut of 0.05 to 0.1 mm commonly are used for roughing cuts. For finishing, the depth of cut is reduced to 0.006 to 0.01 mm.

Grinding machines are available in which the workpiece is held in a chuck for grinding both external and internal cylindrical surfaces. Chucking type external grinders are production type machines for use in rapid grinding of relatively short parts, such as ball-bearing races. Both chucks and collets are used for holding the work, the means dictated by the shape of the workpiece and rapid loading and removal.

In chucking type internal grinding machines, the chuck held workpiece revolves, and a relatively small, high-speed grinding wheel is rotated on a spindle arranged so that it can be reciprocated in and out of the workpiece.

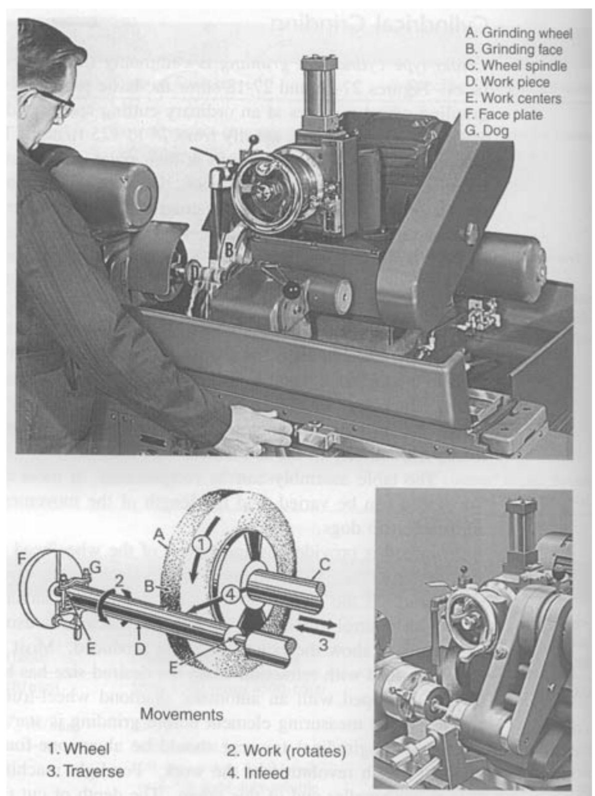


Fig. (9) Cylindrical grinding between centers, lower right: Internal cylindrical grinding on same machine.

Centerless Grinding

Centerless grinding makes it possible to grind both external and internal cylindrical surfaces without requiring the workpiece to be mounted between centers or in a chuck. This eliminates the requirement of center holes in some workpieces and the necessity for mounting the workpiece, thereby reducing the cycle time.

The principle of centerless external grinding is illustrated in Figure 10. Two wheels are used. The larger one operates at regular grinding speeds and does the actual grinding. The smaller wheel is the regulating wheel. It is mounted at an angle to the plane of the grinding wheel. Revolving at a much slower surface speed, usually 15 to 65 m/min, the regulating wheel controls the rotation and longitudinal motion of the workpiece and usually is a plastic- or rubber-bonded wheel with a fairly wide face.

The workpiece is held against the work-rest blade by the cutting forces exerted by the grinding wheel and rotates at approximately the same surface speed as that of the regulating wheel.

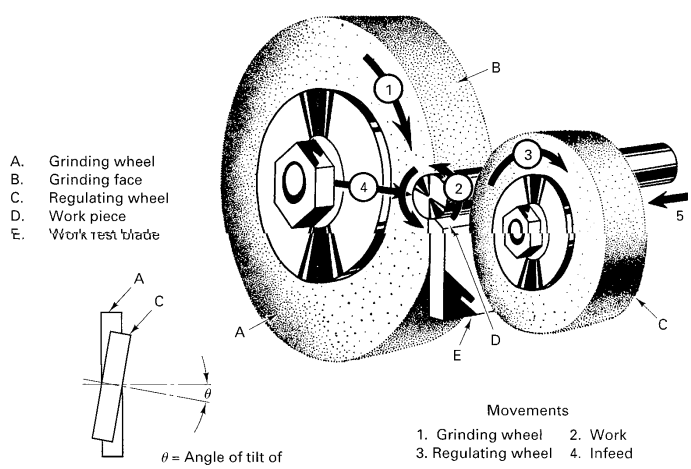


Fig. (10) centerless grinding operation.

Centerless grinding has several important advantages:

1. It is very rapid.
2. Very little skill is required of the operator.
3. It can often be made automatic.
4. Where the cutting occurs, the work is fully supported by the work rest and the regulating wheel. This permits heavy cuts to be made.
5. Because there is no distortion of the workpiece, accurate size control is easily achieved.
6. Large grinding wheels can be used, thereby minimizing wheel wear.

Thus centerless grinding is ideally suited to certain types of mass production operations. The major disadvantages are as follows:

1. Special machines are required that can do no other type of work.
2. The work must be round—no flats, such as keyways, can be present.
3. Its use on work having more than one diameter or on curved parts is limited.
4. In grinding tubes, there is no guarantee that the OD and ID are concentric.

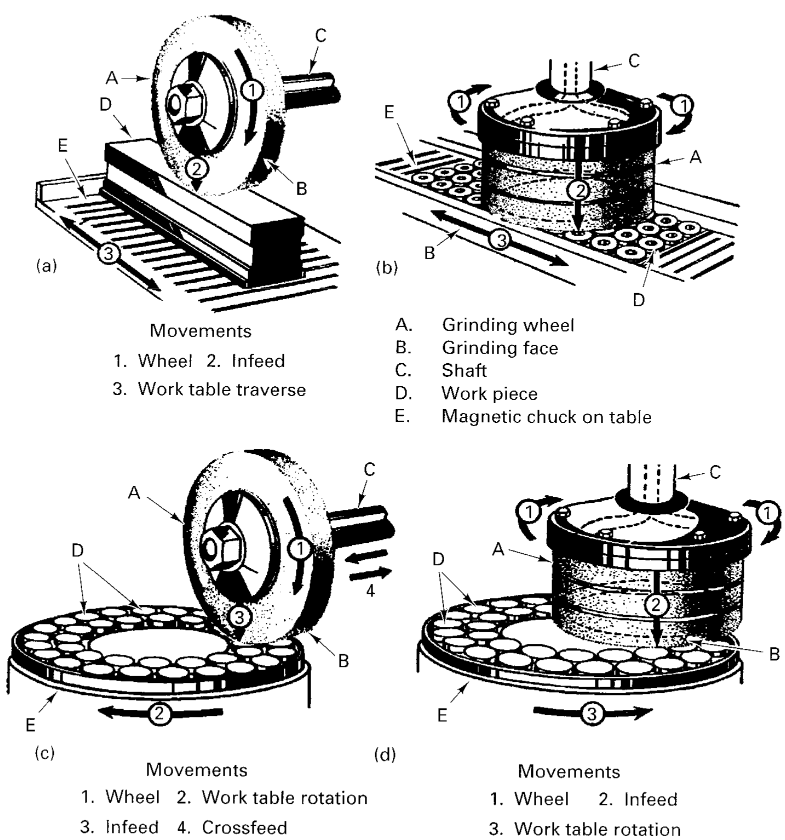
Special centerless grinding machines are available for grinding balls and tapered workpieces. The centerless grinding principle can also be applied to internal grinding, but the external surface of the cylinder must be finished accurately before the internal operation is started. However, it assures that the internal and external surfaces will be concentric. The operation is easily mechanized for many applications.

Surface Grinding Machines

Surface grinding machines are used primarily to grind flat surfaces. There are four basic types of surface grinding machines, differing in the movement of their tables and the orientation of the grinding wheel spindles:

1. Horizontal spindle and reciprocating table,
2. Vertical spindle and reciprocating table,
3. Horizontal spindle and rotary table,
4. Vertical spindle and rotary table.

These machines are illustrated in Figure 11.



The most common type of surface grinding machine has a reciprocating table and horizontal spindle (Figure 11). The table can be reciprocated longitudinally either by handwheel or by hydraulic power. The wheel head is given transverse motion at the end of each table motion, again either by hand wheel or by hydraulic power feed. Both the longitudinal and transverse motions can be controlled by limit switches. Depth of cut on such grinders is controlled by hand wheels or automatically. The size of such machines is designated by the size of the surface that can be ground.

In using such machines, the wheel should over-travel the work at both ends of the table reciprocation, so as to prevent the wheel from grinding in one spot while the table is being reversed. The transverse motion should be one-fourth to three-fourths of the wheel width between each stroke.

Vertical-spindle reciprocating-table surface grinders differ basically from those with horizontal spindles only in that their spindles are vertical and that the wheel diameter must exceed the width of the surface to be ground. Usually, no traverse motion of either the table or the wheel head is provided. Such machines can produce very flat surfaces.

Rotary-table surface grinders can have either vertical or horizontal spindles, but those with horizontal spindles are limited in the type of work they will accommodate and therefore are not used to a great extent. Vertical-spindle rotary-table surface grinders are primarily production-type machines. They frequently have two or more grinding heads and therefore both rough grinding and finish grinding are accomplished in one rotation of the workpiece. The work can be held either on a magnetic chuck or in special fixtures attached to the table.

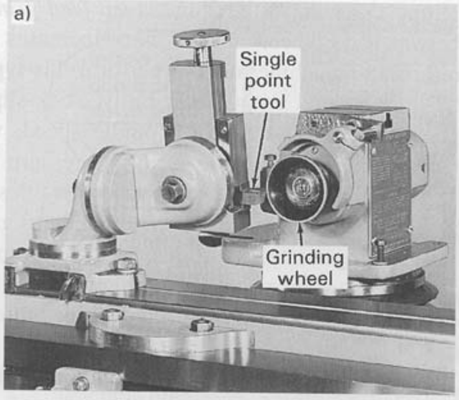
By using special rotary feeding mechanisms, machines of this type often are made automatic. Parts are dumped on the rotary feeding table and fed automatically onto work holding devices and moved past the grinding wheels. After they pass the last grinding head, they are automatically unloaded.

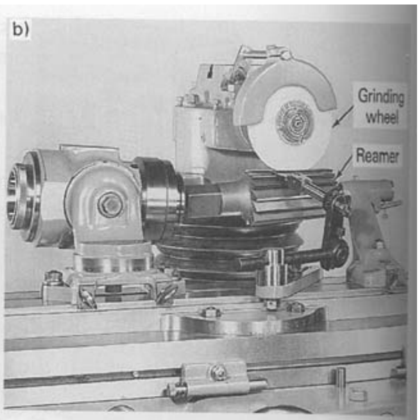
Tool and Cutter Grinders

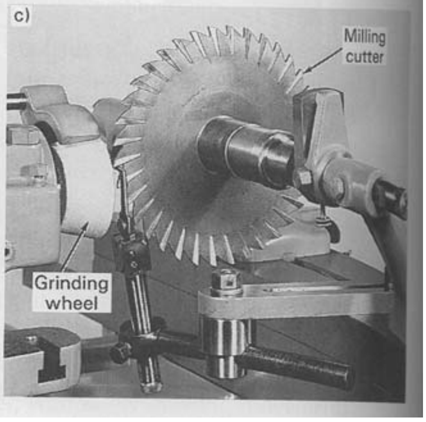
Simple, single-point tools often are sharpened by hand on bench grinders. More complex tools, such as milling cutters, reamers, hobs require more sophisticated grinding machines, commonly called universal tool and cutter grinders. These machines are similar to small universal cylindrical center type grinders, but they differ in four important respects:

1. The headstock is not motorized.
2. The headstock can be swiveled about a horizontal as well as a vertical axis.
3. The wheel head can be raised and lowered and can be swiveled through at 360° rotation about a vertical axis.
4. All table motions are manual. No power feeds being provided.

Specific rake and clearance angles must be created, often repeatedly, on a given tool or on duplicate tools. Tool and cutter grinders have a high degree of flexibility built into them so that the required relationships between the tool and the grinding wheel can be established for almost any type of tool. Although setting up such a grinder is quite complicated and requires a highly skilled worker, after the setup is made for a particular job, the actual grinding is accomplished rather easily. Figure 12 shows several typical setups on a tool and cutter grinder.







Three typical setups for grinding single- and multiple-edge tools on a universal tool and cutter grinder: (a) single-point tool is held in a device that permits all possible angles to be ground; (b) edges of a large hand reamer are being ground; (c) milling cutter is sharpened with a cupped Al_2O_3 grinding wheel.